CHAPTER 10.—METHANE CONTROL IN HIGHWALL MINING

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In This Chapter

- ✓ How inert gas works to prevent methane explosions
- ✓ How inert gas is generated and delivered at highwall mines
- ✓ Volume and quality requirements for inert gas at highwall mines
- ✓ How an inert gas system is operated

and

- ✓ Precautions to take during mining to prevent methane explosions

This chapter discusses a method, originally developed by Volkwein and Ulery [1993], to prevent methane explosions during highwall mining. In highwall mining, a horizontal auger or a mining machine enters the coal seam from a surface mine pit at the bottom of a highwall, and the coal is mined out from a series of parallel holes. Explosions can be prevented by injecting inert gas into each hole as it is mined.

Coal near the surface has lost most of its methane gas over time. However, in recent years, surface mining has been used for deeper reserves of coal. This trend toward mining deeper reserves has increased the chance of encountering methane, and methane explosions at highwall mining operations have resulted in injuries.

HOW INERT GAS WORKS TO PREVENT METHANE EXPLOSIONS

A methane explosion requires the presence of sufficient amounts of both methane and oxygen, as well as an ignition source. If the methane cannot be reduced and the ignition source cannot be eliminated, then explosions may be prevented by adding an inert gas, which contains little to no oxygen, to the mixture [FWQA 1970]. Just how much inert gas must be added depends on the mining rate, as well as the composition of the inert gas.

An explosibility diagram can be used to show whether a methane mixture is explosive after inert gas is added [Zabetakis et al. 1959] (Figure 10–1). This diagram indicates that gas mixtures fall into one of three range categories—explosive, explosive when mixed with air, and nonexplosive—depending on the percentage of methane and percentage of "effective inert." Effective inert is calculated from the percentage of "excess nitrogen"[3] and percentage of carbon dioxide in the mixture.

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[3]The percentage of excess nitrogen is the percentage of nitrogen in the sample minus the percentage of "normal nitrogen." Normal nitrogen is calculated from the ratio of nitrogen to oxygen normally found in air—a factor of 3.8.

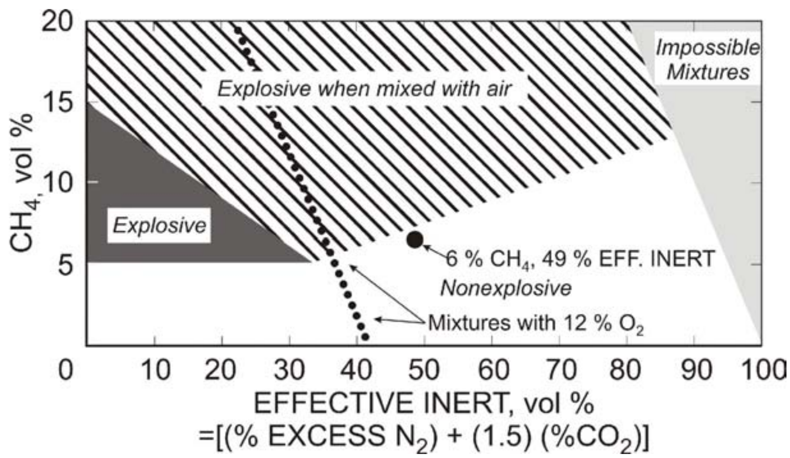

Figure 10–1.—Explosibility diagram for methane-air-inert gas mixtures.

To calculate the effective inert, suppose, for example, that inert gas is added to a methane-air mixture and that a gas analysis shows that the final mixture has 10% oxygen, 6% carbon dioxide, 6% methane, and 78% nitrogen. The effective inert is then determined in three steps. First, in this example, the oxygen percentage is 10%, so the percentage of normal nitrogen is 3.8 times 10%, or 38%. Second, since the percentage of excess nitrogen is the percentage of nitrogen in the sample minus the percent of normal nitrogen, the excess nitrogen is 78% minus 38%, or 40%. Third, according to the equation shown in Figure 10–1, since the carbon dioxide in the sample is 6%, the effective inert is now 40% + (1.5 × 6%), or 49%.[4]

The point representing a gas mixture containing 6% methane and 49% effective inert is shown in Figure 10–1, placing this mixture in the "nonexplosive" range. To minimize the explosion hazard during highwall mining, the objective is to add enough inert gas to keep the final mixture well out of the explosive range.

A handy rule of thumb is that the oxygen content of the mixture must be reliably maintained below 12%. Nitrogen-oxygen-methane mixtures with 12% oxygen fall along the dotted line in Figure 10–1. Mixtures with less than 12% oxygen fall to the right of this line and are either "nonexplosive" or "explosive when mixed with air."

The explosibility of mixtures with more than 12% oxygen must be evaluated in the context of Figure 10–1. For example, a mixture of 15% methane, 15% oxygen, and 70% nitrogen has 13% effective inert, so it falls in the "explosive when mixed with air" range.

THE INERT GAS SYSTEM

Preventing explosions on highwall mining machines using inert gas requires a source of inert gas and a method to keep the hole completely filled with inert gas as it is mined. As Figure 10–1 indicates, if an inert gas completely displaces all of the air in the hole, then any gas source having an effective inert concentration of 34% or greater (or an oxygen concentration of 12% or less) will prevent methane from igniting. To ensure that all of the air in the hole is displaced, the

[4]Carbon dioxide has been found to be 50% more effective than nitrogen in inerting, so a multiplying factor of 1.5 is used.

volume of inert gas delivered to the hole must equal or exceed the volume of coal extracted from the hole.

Auger mining. Logical sources of inert gas for auger mining are the auger machine's diesel engine and an auxiliary gasoline engine. The inert gas system that was originally developed by Volkwein and Ulery [1993] is shown in Figure 10–2.

The Volkwein and Ulery system was evaluated at an auger mining operation at a surface mine in Kentucky. During initial testing of their system, Volkwein and Ulery found that the oxygen content of the diesel engine powering the auger (a Cummins turbocharged 270) was not always low enough to prevent explosions. The diesel engine exhaust oxygen concentrations range from 8% at full load to 17% at no load (typical for diesel engines).

It is known that gasoline engine exhaust has consistently lower oxygen concentrations than diesel engine exhaust, so a 305-in^3 gasoline engine was used as the primary source of the inert gas. This gasoline engine was mounted on the roof of the auger drill, and a new catalytic converter was installed on its exhaust manifold. The catalytic converter burned excess hydrocarbons and carbon monoxide, further lowering the oxygen content of the exhaust. This engine was operated at 3,600–3,900 rpm. Although the gasoline engine alone produced oxygen concentrations in the 1%–4% range, the exhaust volume was insufficient to keep the hole completely filled with inert gas. To make up for this lack of volume, a portion of the diesel engine exhaust was added to the gasoline engine exhaust.

As shown in Figure 10–2, the diesel engine exhaust was conducted from the engine muffler (no catalytic converter was used on the diesel) to the roof of the auger drill through a flexible 5-in steel pipe. This flexibility allowed the engine carriage to travel freely as the auger drill moved forward. The volume of diesel exhaust entering the auger hole was controlled by a critical orifice restriction, selected to allow equal proportions of diesel and gasoline engine

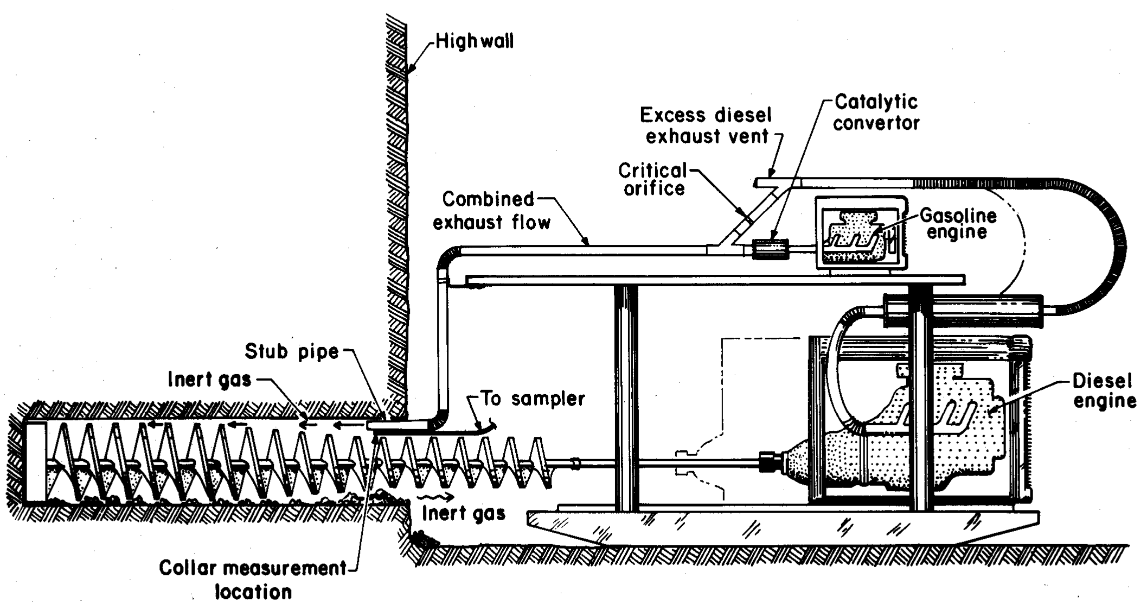

Figure 10–2.—Schematic of inert gas system for auger mining.

exhaust. The remaining diesel exhaust was vented at the roof of the auger drill. The combined exhaust flows were routed through a section of 5-in-diam flexible pipe that connected to a vertical descending pipe that brought the exhaust to the level of the hole. A 7-ft length of 3-in stub pipe extended the exhaust gas discharge about 5 ft into the hole.

With this system, inert gas mixture was released at the collar of the hole, reaching the cutting head by simple displacement of the extracted coal. The inert gas followed the auger head into the hole. As angering proceeded, the hole remained in an inert condition provided that a sufficient volume of inert gas always flowed out of the hole to keep out the surrounding air.

Ripper-head miners. Adapting inert gas technology from auger miners to ripper-head miners involves few changes. Ripper-head systems are in use in Australia with the addition of an automated stub pipe that discharges the inert gas farther into the hole. The inert gas has to be discharged farther into the hole because the hole is wider. With a short stub pipe, the wider openings may allow equipment movement and external wind to dilute the inert gas before it can displace the removed coal.

An inert gas system designed and used by a mine operator does not have to be identical to the one designed by Volkwein and Ulery. However, any inert gas generation system must deliver an adequate quantity of gas with a sufficiently low oxygen concentration.

SYSTEM REQUIREMENTS AND OPERATION

Inert gas quantity. In order for inert conditions to be maintained at the cutting head of the auger string, the volume of inert gas produced must exceed the volume of coal removed and the inert gas must be supplied continuously as augering proceeds. This keeps the surrounding air out of the hole.

During testing of the system designed by Volkwein and Ulery [1993], time studies of coal removal showed that auger sections 17 through 27 required an average of 102 sec per cycle. Of that cycle time, approximately 20 sec was required for retraction of the kelly bar, leaving 82 sec for coal removal. The fastest cycle time recorded was 70 sec for coal removal. Each added auger section removed a coal cylinder 3.25 ft in diameter by 6 ft long, or 49.7 ft^3 of coal. The average coal removal rate was calculated to be 35.0 ft^3/min, with a maximum removal rate of 42.0 ft^3/min. At greater hole depth (auger numbers 55 through 60), the average removal rate was calculated to be 27.0 ft^3/min, with a maximum rate of 30.3 ft^3/min. Smaller diameter augers or slower penetration speeds will decrease this volume, and vice versa.

Since the engine gas cools and water vapor condenses inside the auger hole, the amount of inert gas actually available is the cooled gas, not the hot gas. When the volume of hot gas is measured, a large correction factor must be used to determine the available inert gas volume. A correction factor of 0.125 was obtained during the testing, so 0.125 was multiplied by the hot exhaust gas volume to yield the available inert gas volume.[5] Hot gas velocities can be measured with a pitot tube installed in the gas delivery pipe. The readings must be corrected for air density using a value of 0.0415 lb/ft^3 to reflect the elevated temperature of about 500 °F.

For the system tested, the minimum cooled gas volume found during testing with the combined engine exhaust was 50 ft^3/min. The maximum rate of coal removal was 42 ft^3/min. This calculates to a 16% excess volume of inert gas for the worst-case conditions—minimum gas volume and maximum coal removal.

Oxygen concentration. If the oxygen concentration can be maintained at 12% or less, measurement of the oxygen concentration alone is sufficient to indicate the inert condition of the gas. These measurements could be made with a handheld oxygen detector or an in-line continuous oxygen detector.

During testing [Volkwein and Ulery 1993], a level of 12% oxygen was maintained along with 6% carbon dioxide. Since combustion engines always produce carbon dioxide in addition to lowering the oxygen level, the presence of carbon dioxide will provide a safety factor if the oxygen is 12% or less.

Placement of the stub pipe and purging the starter hole. For inert gas to be continuously maintained at the front of the auger hole, the region just inside the collar of the hole must be continuously provided with inert gas. However, when the head and lead guide augers are starting the drilling, there is no room to insert the stub pipe. The ideal time to extend the stub pipe into the collar of the hole is after a smaller-diameter auger is attached and the hole is just deep enough to make room for the stub pipe (see Figure 10–2). Then the auger is stopped and the stub pipe is installed. After the stub pipe is installed, the auger is not rotated until the starter hole is purged with inert gas.

When placing a stub pipe, be certain that it extends at least 5 ft into the hole. The jet from a shorter stub pipe might entrain outside air.

Purging of the starter hole is necessary because of the air drawn in by the head and lead guide augers. The time required to purge the starter hole depends on the volume of the hole and the gas flow rate. During testing in the Volkwein and Ulery study, the empty hole volume was 216 ft^3 (3.25 ft diameter by 26 ft deep) with about one-half of this volume occupied by the auger steel and cut coal, leaving 108 ft^3. At an inert gas flow rate of 56 ft^3/min, one complete air change occurred in less than 2 min. During testing, engines were run for about 4 min to fill the starter hole with inert gas before augering proceeded.

When insertion of the inert gas stub pipe is delayed, deeper starter holes require much longer times to become inert. For example, during testing when the hole was augered 44 ft before inserting the stub pipe, it took about 12 min to reach inert conditions. By contrast, a 26-ft hole

[5]This seems like a surprisingly large reduction in volume, but much of it is due to water vapor condensation.

required only 4 min. As a result, timely placement of the stub pipe is important so that the starter hole does not become too deep before inert gas is added.

PRECAUTIONS TO TAKE DURING MINING

An inert gas system will not prevent explosions if it is not operating properly. During mining, the operator of the system must ensure that the concentration of engine exhaust gases stays at or below 12% oxygen, that the workplace is free of carbon monoxide, and that there is a steady movement of gas from the hole.

The oxygen level in the engine exhaust gases is easily measured with a real-time oxygen indicator that has a readout and provides a warning if the level rises above 12%.

Because the exhaust gas from engines contains carbon monoxide, personal exposure to carbon monoxide should be monitored. During the testing by Volkwein and Ulery [1993], the highest personal exposure to carbon monoxide measured with the passive dosimeters was less than 20 ppm. This occurred near the auger pin puller. The conveyor side helper had only a trace of exposure, and the machine operator had no detectable exposure. The combination of dilution and distance from the collar of the hole accounted for the observed low personal exposure to carbon monoxide.

A steady movement of inert gas from the hole will keep out the surrounding air. This requires the operator to observe the direction of movement of dust or smoke during periods of maximum auger penetration. This direction of movement should always be out of the hole.

Auger removal. The inert gas system should be left on during auger removal so that the dilution of gas in the hole takes place with inert gas rather than with air. However, auger removal is usually rapid—about 25 sec per cycle, with 15 sec of that cycle required for pin pulling and stacking of the auger. During the testing by Volkwein and Ulery [1993], rapid removal of the auger steel volume slightly exceeded the inert gas volume, but this excess was not considered to be significant.

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